GPDs with CLAS12

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Overview

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2. **CLAS 12**
3. **Proposed measurements**
   - Proton DVCS
   - Neutron DVCS
   - Other highlights
4. **GPD extraction**
5. **Summary**

Introduction

Physical content of GPDs

Momentum distributions in the transverse plane

$$q_X(x,\vec{b}_\perp) = \int \frac{d^2\vec{\Delta}_\perp}{(2\pi)^2} H(x,0,t) e^{-i\vec{\Delta}_\perp\cdot\vec{b}_\perp} - \frac{1}{2M}\frac{\partial}{\partial b_y}\int \frac{d^2\vec{\Delta}_\perp}{(2\pi)^2} E(x,0,t) e^{-i\vec{\Delta}_\perp\cdot\vec{b}_\perp}$$

M. Burkardt, Phys. Rev. **D62**, (2000) 071503
$\xi \neq 0$ in M. Diehl, Eur. Phys. J. **C25** (2002) 223

Energy-momentum tensor of q flavored quarks

$$\langle p_2|\hat{T}^q_{\mu\nu}|p_1\rangle = \bar{U}(p_2)\left[M_2^q(t)\frac{P_\mu P_\nu}{M} + J^q(t)\frac{i(P_\mu\sigma_{\nu\rho}+P_\nu\sigma_{\mu\rho})\Delta^\rho}{2M} + d_1^q(t)\frac{\Delta_\mu\Delta_\nu - g_{\mu\nu}\Delta^2}{5M}\right] U(p_1)$$

To measure gravitational FFs : graviton scattering or GPDs identities :

$$J^q(t) = \frac{1}{2}\int_{-1}^{1} dx\, x\left[H^q(x,\xi,t) + E^q(x,\xi,t)\right], \quad M_2^q(t) + \frac{4}{5}d_1(t)\xi^2 = \frac{1}{2}\int_{-1}^{1} dx\, xH^q(x,\xi,t)$$

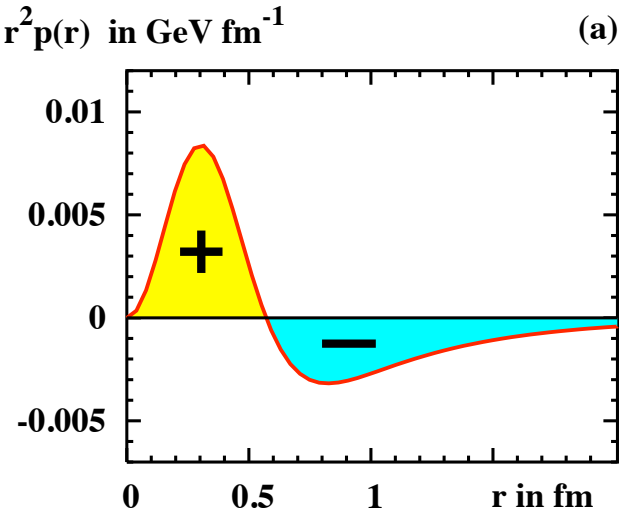
(Ji's sum rule)

Physical content of GPDs : Energy-momentum tensor of q flavored quarks

$$\langle p_2 | \hat{T}^q_{\mu\nu} | p_1 \rangle = \bar{U}(p_2) \left[M_2^q(t) \frac{P_\mu P_\nu}{M} + J^q(t) \frac{i(P_\mu \sigma_{\nu\rho} + P_\nu \sigma_{\mu\rho})\Delta^\rho}{2M} + d_1^q(t) \frac{\Delta_\mu \Delta_\nu - g_{\mu\nu}\Delta^2}{5M} \right] U(p_1)$$

$$M_2(t) \longleftrightarrow T_{00} : \text{mass distributions inside the hadron}$$
$$J(t) \longleftrightarrow T_{0i} : \text{angular momentum distributions}$$
$$d_1(t) \longleftrightarrow T_{ij} : \text{forces and pressure distributions}$$

Large N_c χQSM from K.Goeke *et al.* in Phys. Rev. **D75** (2007) 094021



$$\text{Stability} \Rightarrow \int_0^\infty dr\, r^2 p(r) = 0$$

$r < 0.57$ fm $\Rightarrow p(r) > 0 \leftrightarrow$ repulsion (quark core)

$r > 0.57$ fm $\Rightarrow p(r) < 0 \leftrightarrow$ attraction (pion cloud)

Access to GPDs : the DVCS process

Observables in the Bjorken limit

$$\gamma^* p \to \gamma p'$$

Bjorken regime :

$Q^2 \to \infty$,

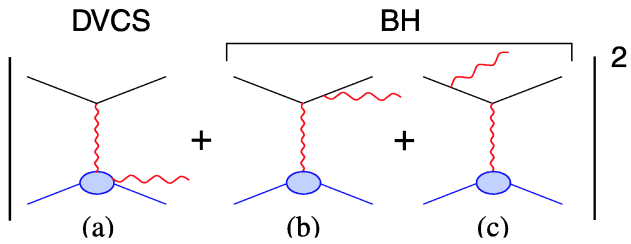
$\nu \to \infty$,

$x_B = Q^2/2M\nu$ fixed

$\left(\xi \to \frac{x_B}{2-x_B}\right)$

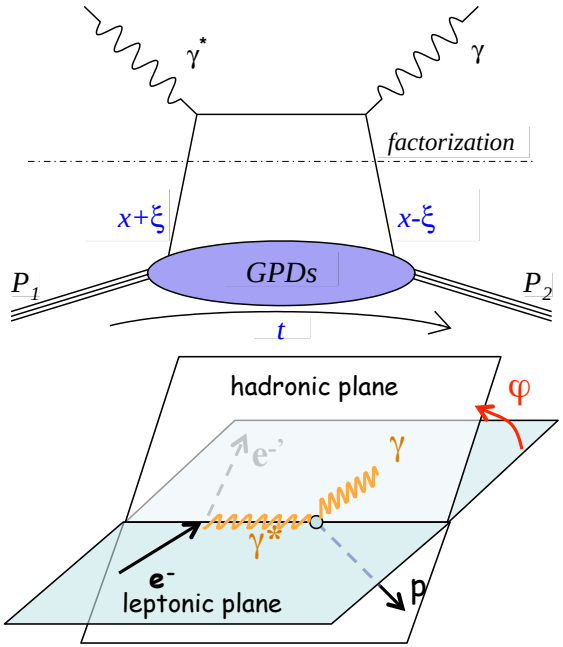
Müller, Ji, Radyushkin (1994-96)

$$ep \to ep\gamma$$

$\sigma(ep \to ep\gamma) \propto$ 

Diehl, Gousset, Pire, Ralston (1997)

Belitsky, Müller, Kirchner (2002-10)



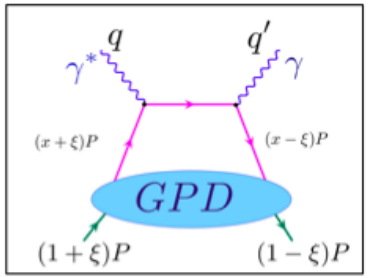
$$A_{LU} = \frac{d^4\sigma^{\rightarrow} - d^4\sigma^{\leftarrow}}{d^4\sigma^{\rightarrow} + d^4\sigma^{\leftarrow}} \overset{\text{twist-2}}{\approx} \frac{\alpha \sin\phi + \cdots}{1 + \beta\cos\phi + \cdots}$$

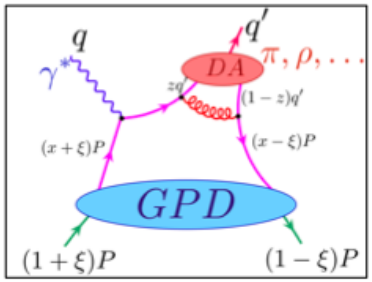
$$\alpha \propto \left(F_1\mathcal{H} + \xi G_M\tilde{\mathcal{H}} - \frac{t}{4M^2}F_2\mathcal{E}\right)$$

$$\mathcal{H}(\xi,t) = \pi\sum_q Q_q^2\left[H^q(\xi,\xi,t) - H^q(-\xi,\xi,t)\right]$$

$$A_{UL} \propto \left(F_1\tilde{\mathcal{H}} + \xi G_M\mathcal{H} + G_M\frac{\xi}{1+\xi}\mathcal{E} + \cdots\right)\sin\phi$$

Observables sensitivities to GPD





	$\mathcal{I}$m	$\mathcal{R}$e
$\mathcal{H}$	A_{LU}	σ , A_{LL}
$\tilde{\mathcal{H}}$	A_{UL}	
$\mathcal{E}$	A_{UT} , A_{LT}	

DVCS

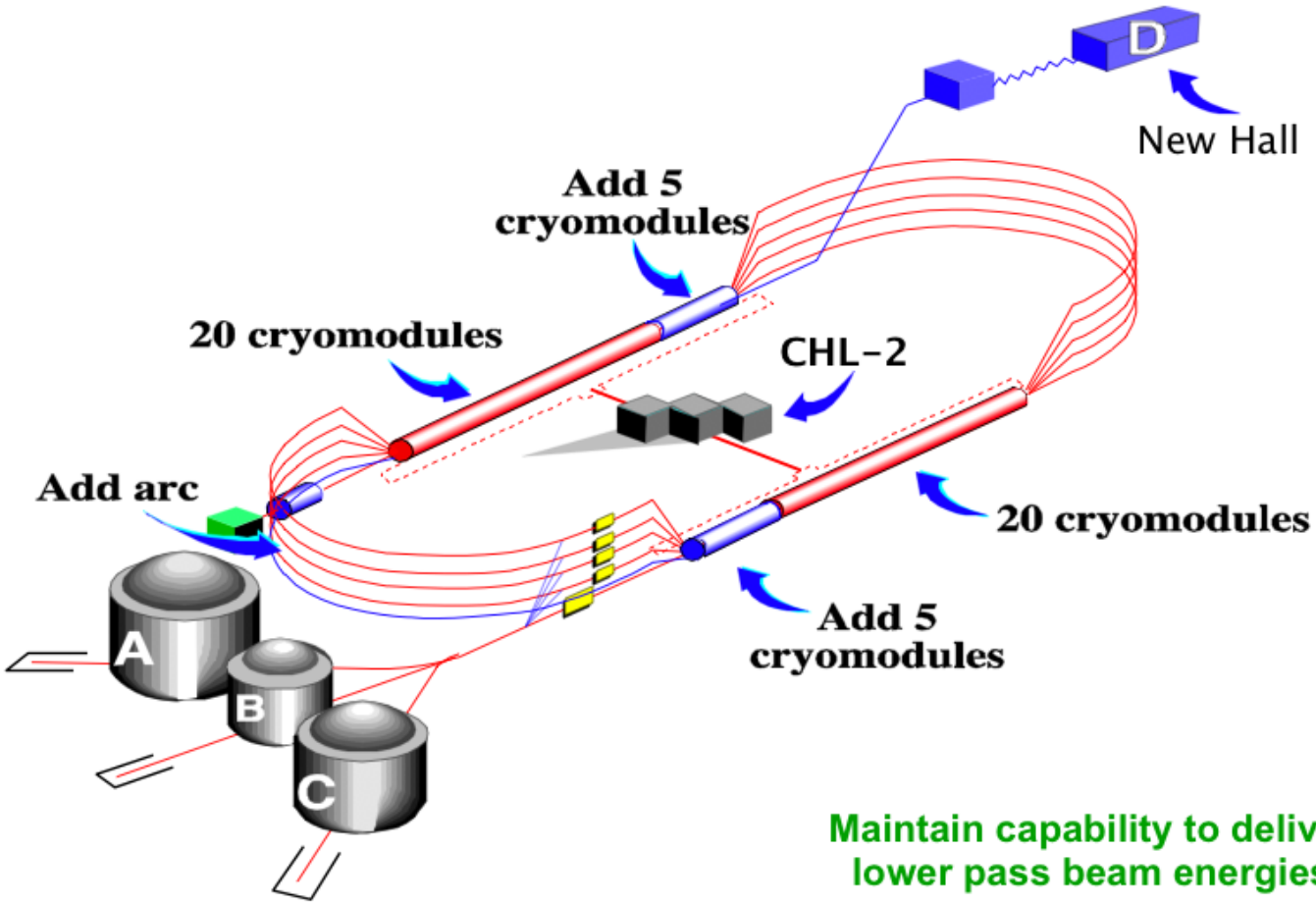
	Meson	Flavor
$\tilde{\mathcal{H}}$,$\tilde{\mathcal{E}}$	π^+	$\Delta u - \Delta d$
	π^0	$2\Delta u + \Delta d$
	η	$2\Delta u - \Delta d + 2\Delta s$
$\mathcal{H}$,$\mathcal{E}$	ρ^+	$u - d$
	ρ^0	$2u + d$
	ω	$2u - d$
	ϕ	s

DVMP

Only a global analysis of all observables can disentangle GPDs

12 GeV upgrade

JLab12

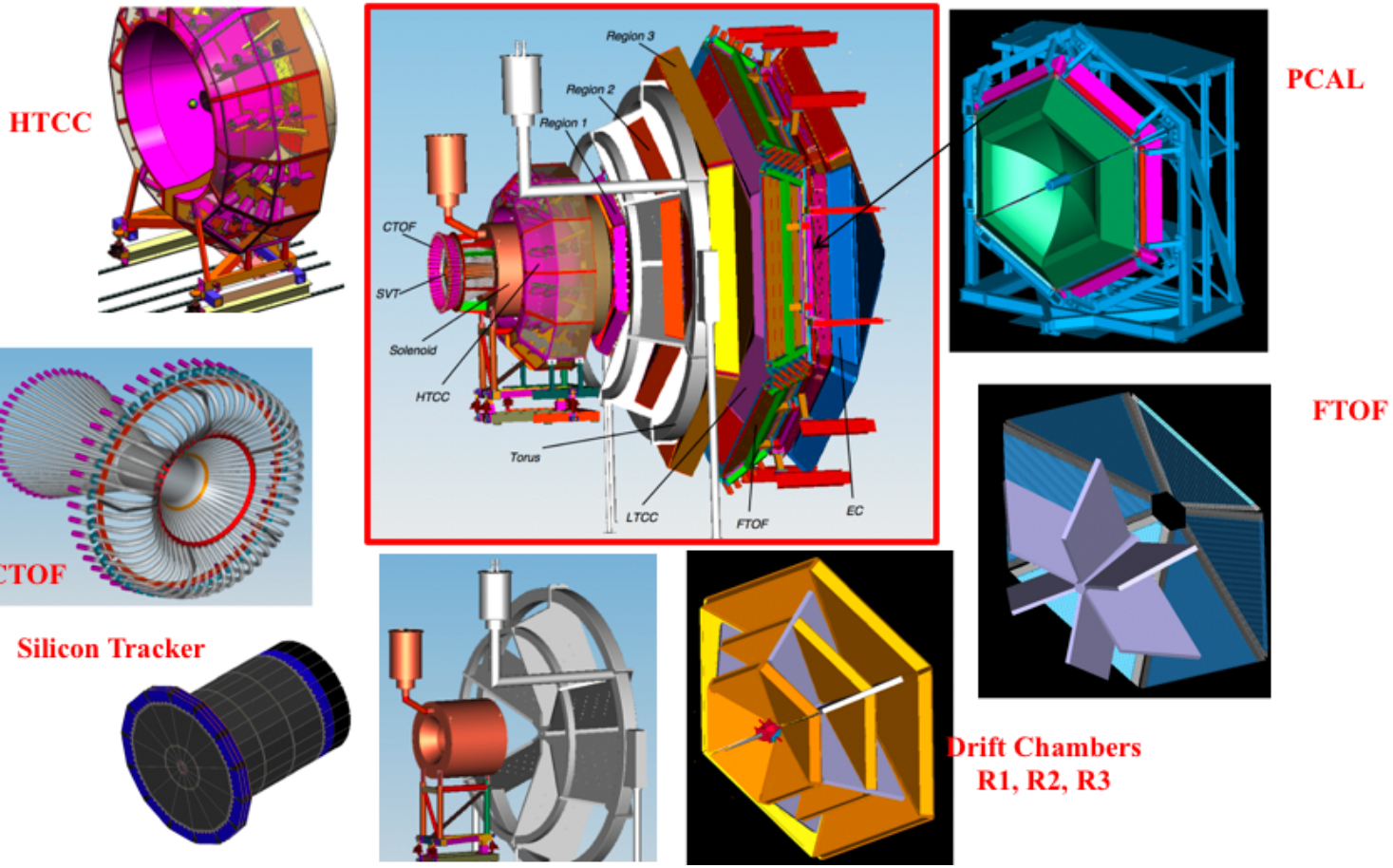


Maintain capability to deliver lower pass beam energies

Enhanced capabilities in existing Halls

Upgraded apparatus

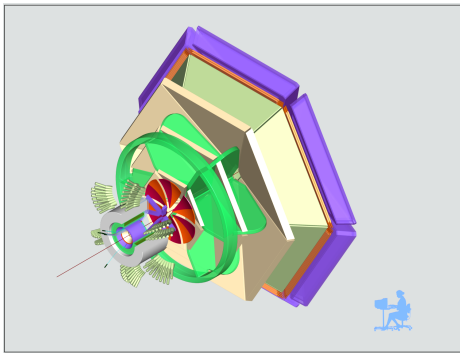
Higher energy, luminosity, hermiticity, analyzing power

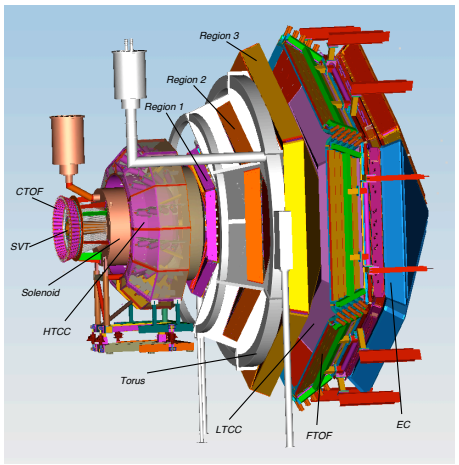


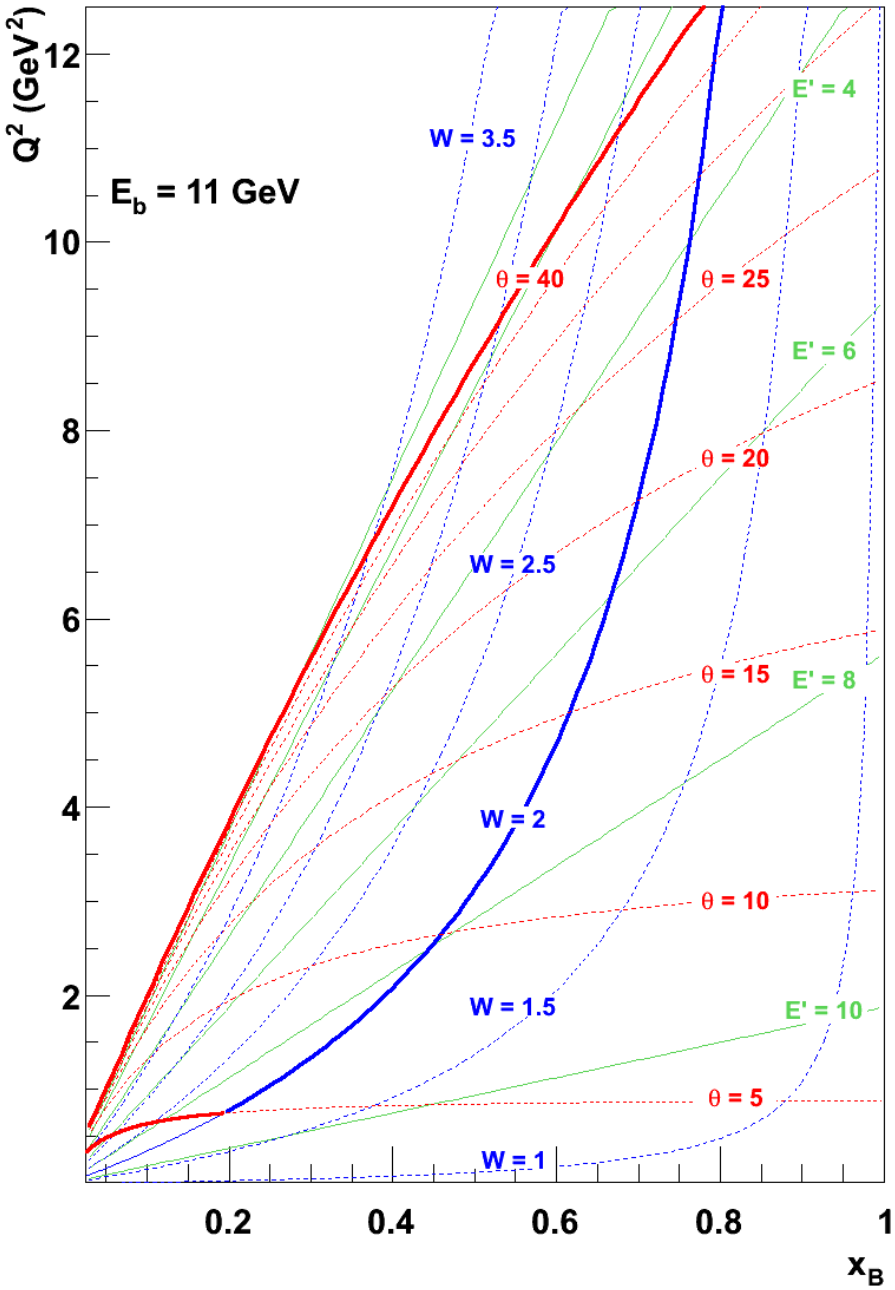
Upgraded apparatus

	Forward detector	Central detector
Angular range		
Tracks	$5 - 40^\circ$	$35 - 125^\circ$
Photons	$2.5 - 40^\circ$	n.a.
Resolution		
$\delta p/p$	< 1% @ 5 GeV/c	5% @ 1.5 GeV/c
$\delta\theta$	< 1 mr	< 10-20 mr
$\delta\phi$	< 3 mr	< 5 mr
Photon detection		
Energy	> 0.15 GeV	n.a.
$\delta\theta$	4 mr @ 1 GeV	n.a.
Neutron detection		
Efficiency	< 0.7	under dev.
Particle ID		
e/π	Full range	n.a.
π/p	Full range	< 1.25 GeV/c
π/K	Full range	< 0.65 GeV/c
K/p	< 4 GeV/c	< 1 GeV/c
$\pi \rightarrow \gamma\gamma$	Full range	n.a.
$\eta \rightarrow \gamma\gamma$	Full range	n.a.

Upgraded apparatus





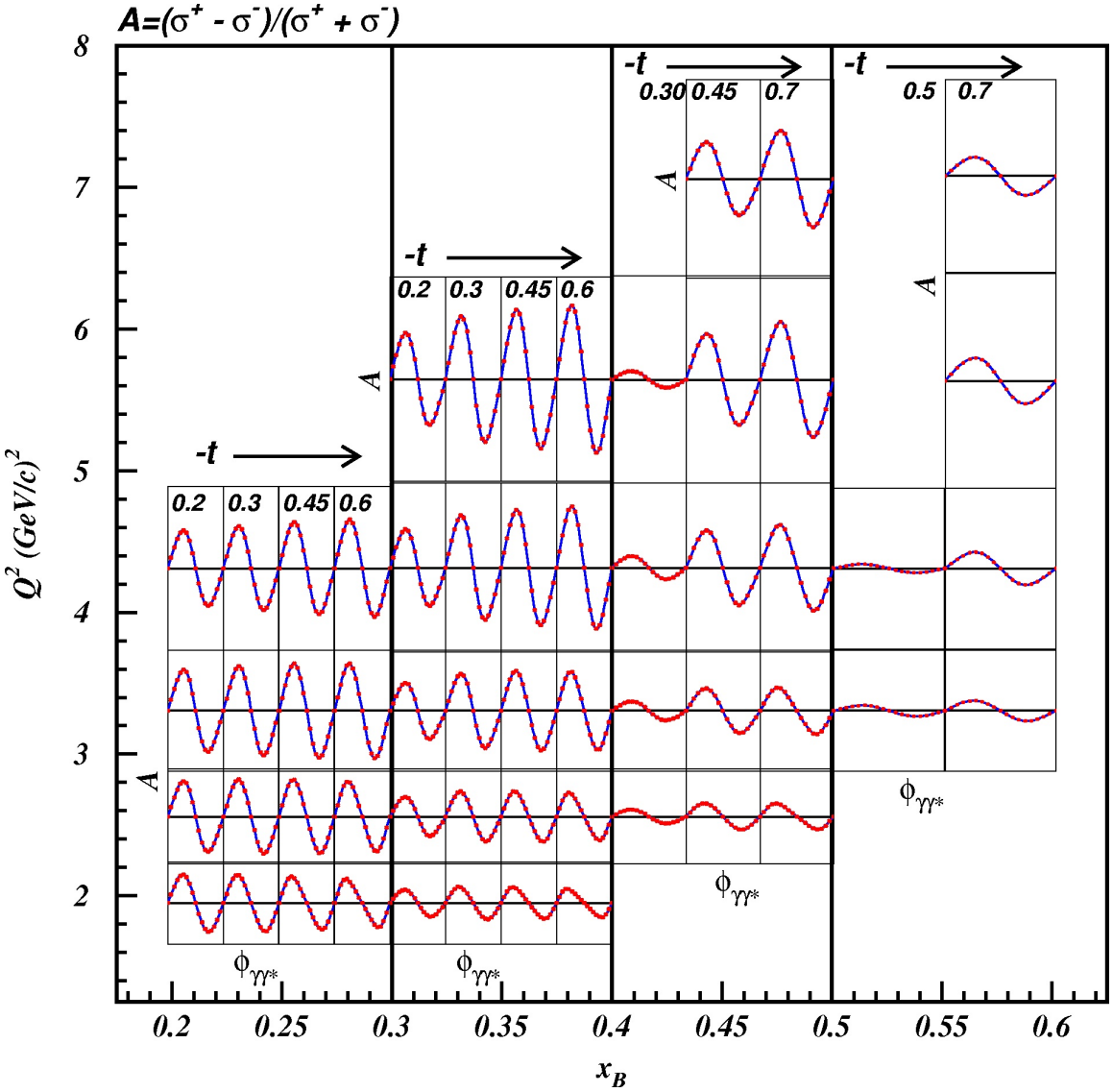


GPD program

Proton DVCS

Proton DVCS A_{LU}

80 days @ $\mathcal{L} = 10^{35}$ cm^{-2}s^{-1} with 85% polarized beam



Statistical uncertainties from 1 % (low Q^2) to 10 % (high Q^2)

Proton DVCS A_{LU}

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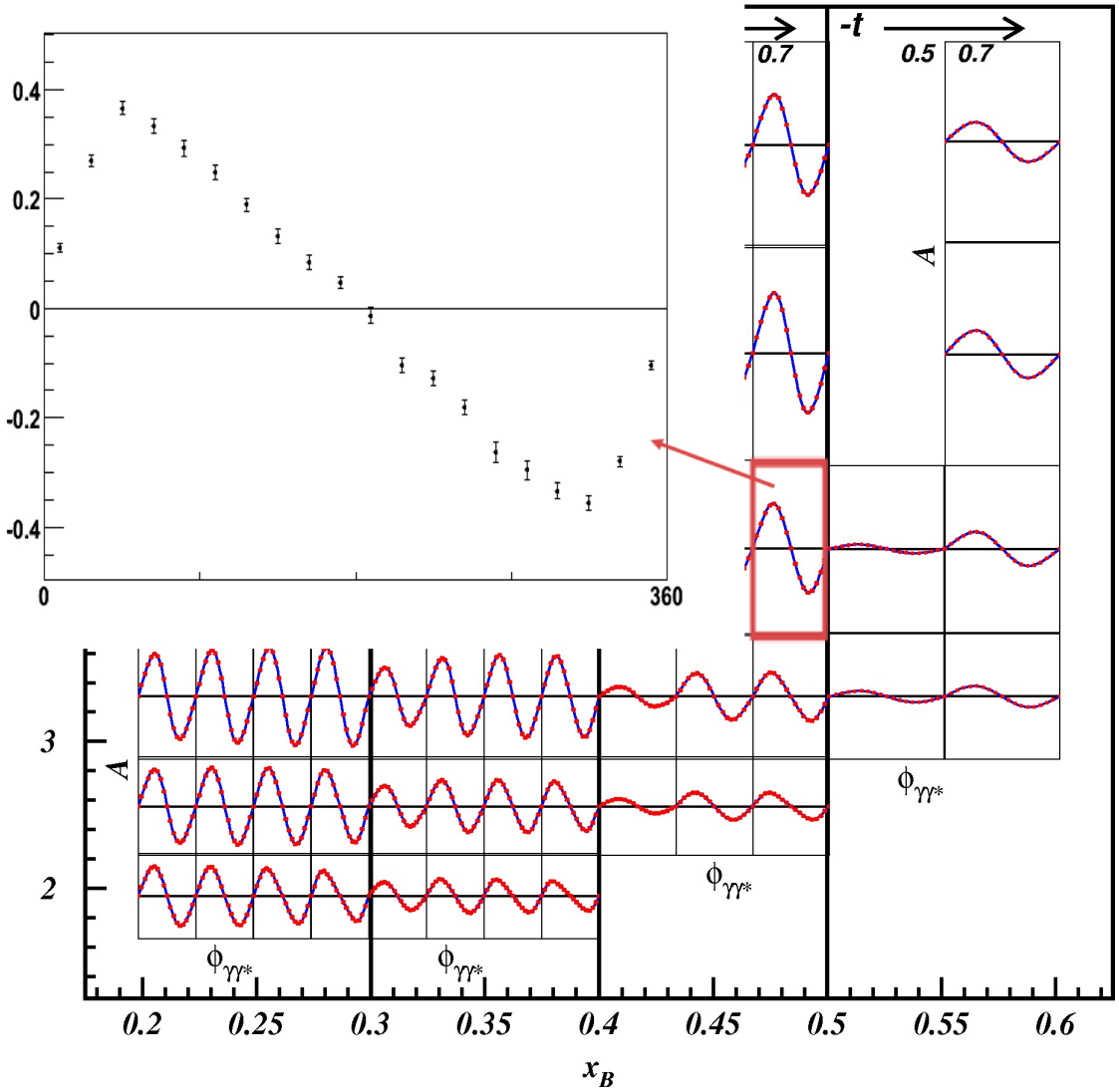

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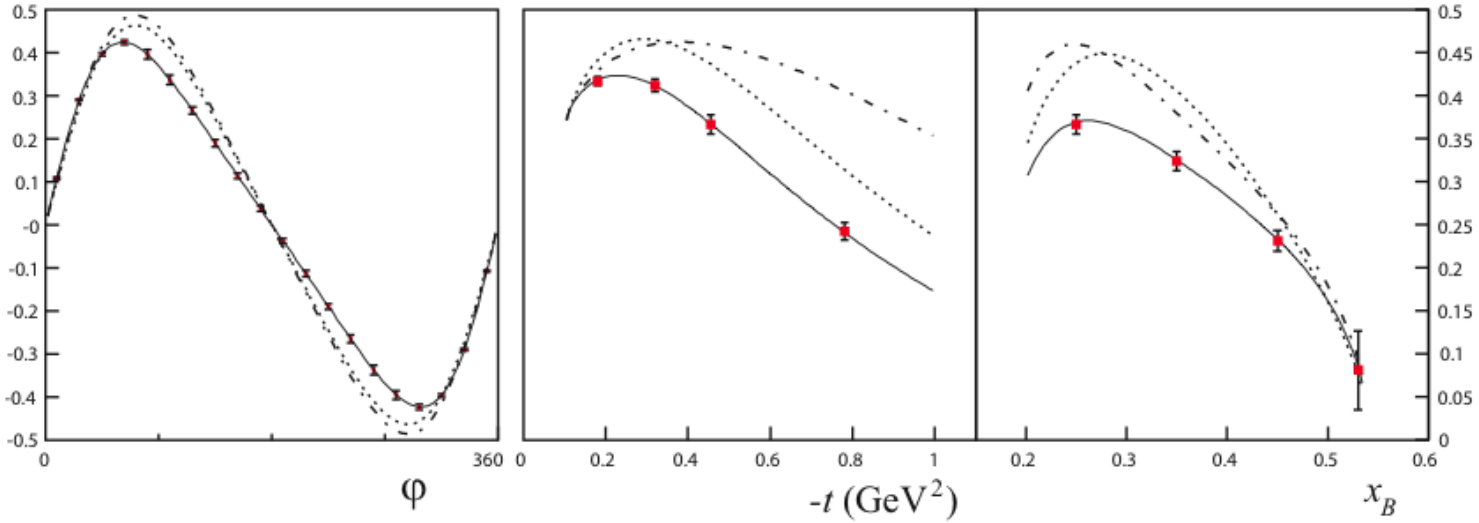
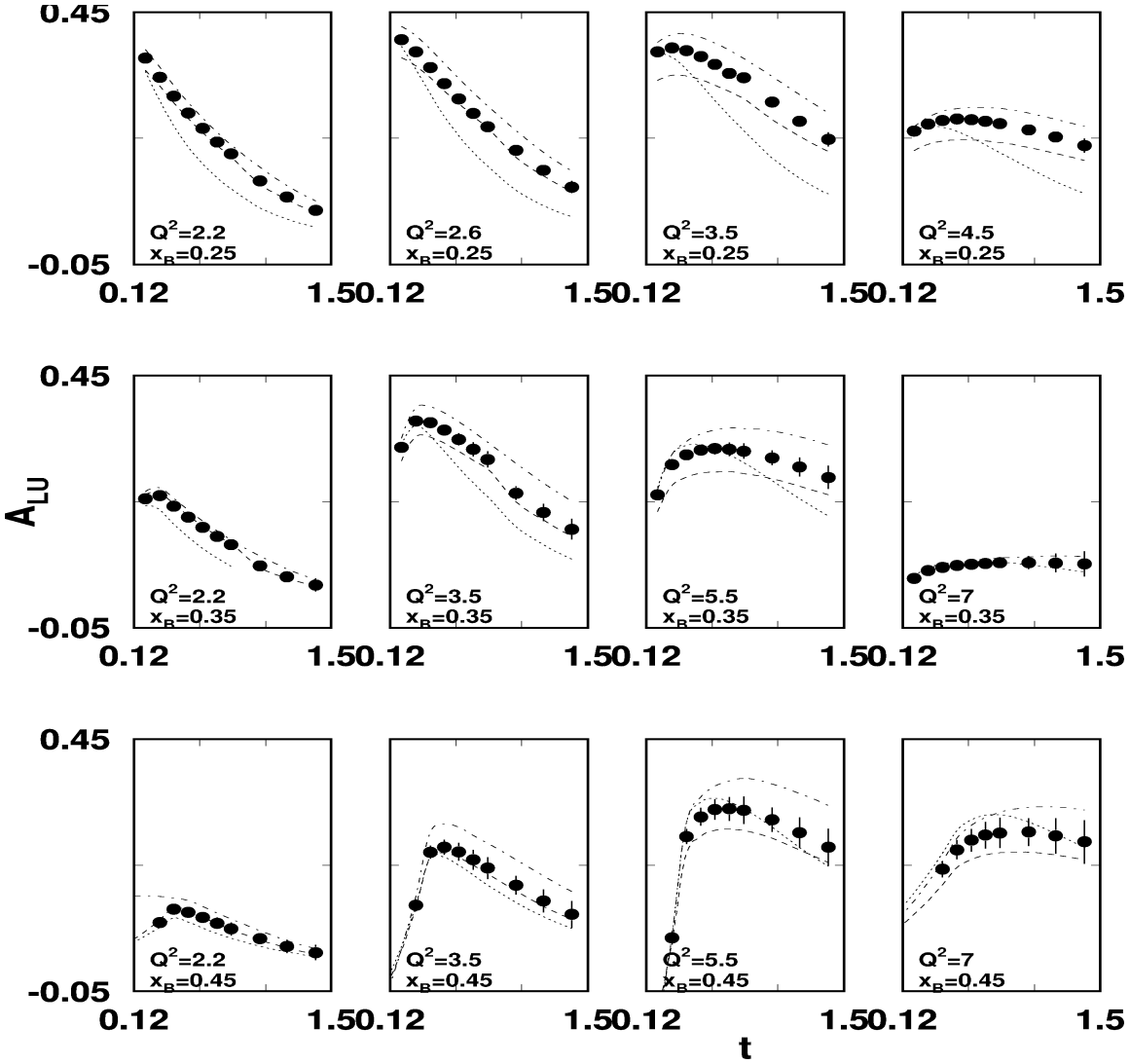


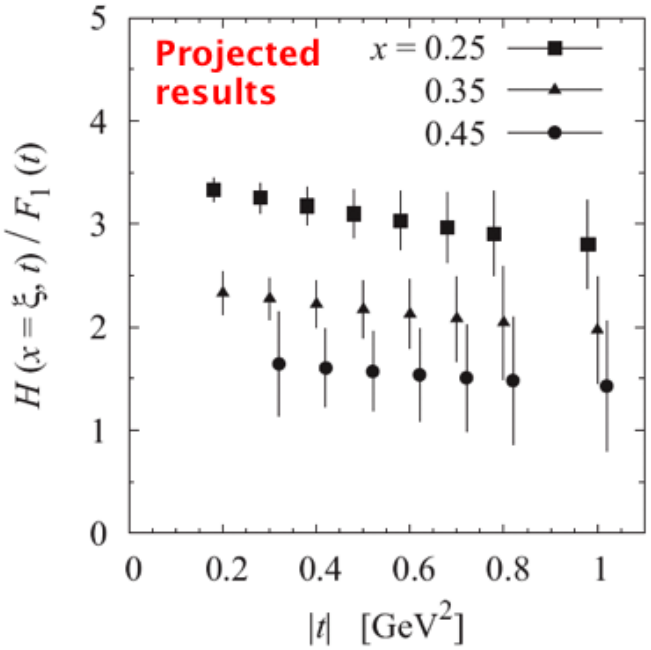
Dotted curve : no D-term, dashed-dotted : factorized t-dependence
$Q^2 = 3.3$ GeV^2, $x_B = 0.2$ (left and middle), $-t = 0.45$ GeV^2 (left and right)

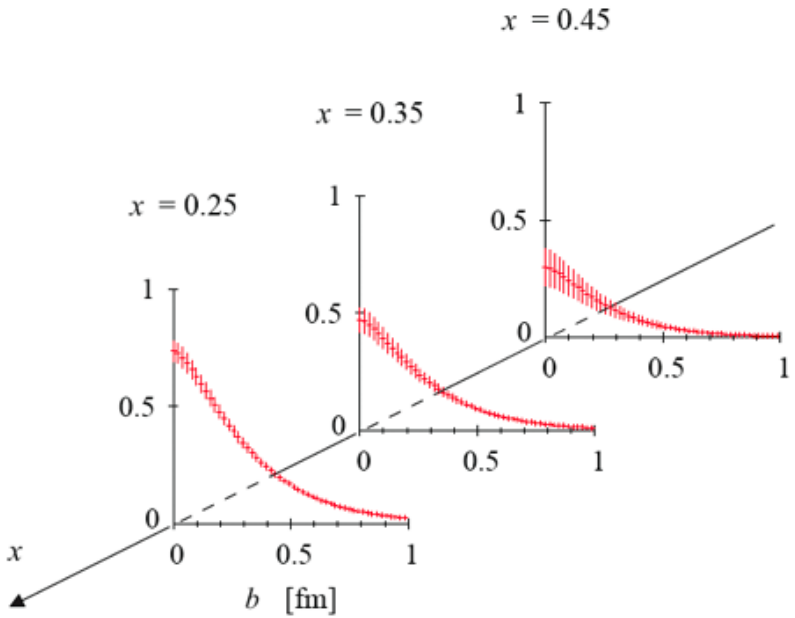
Proton DVCS A_{LU}



Proton DVCS A_{LU}

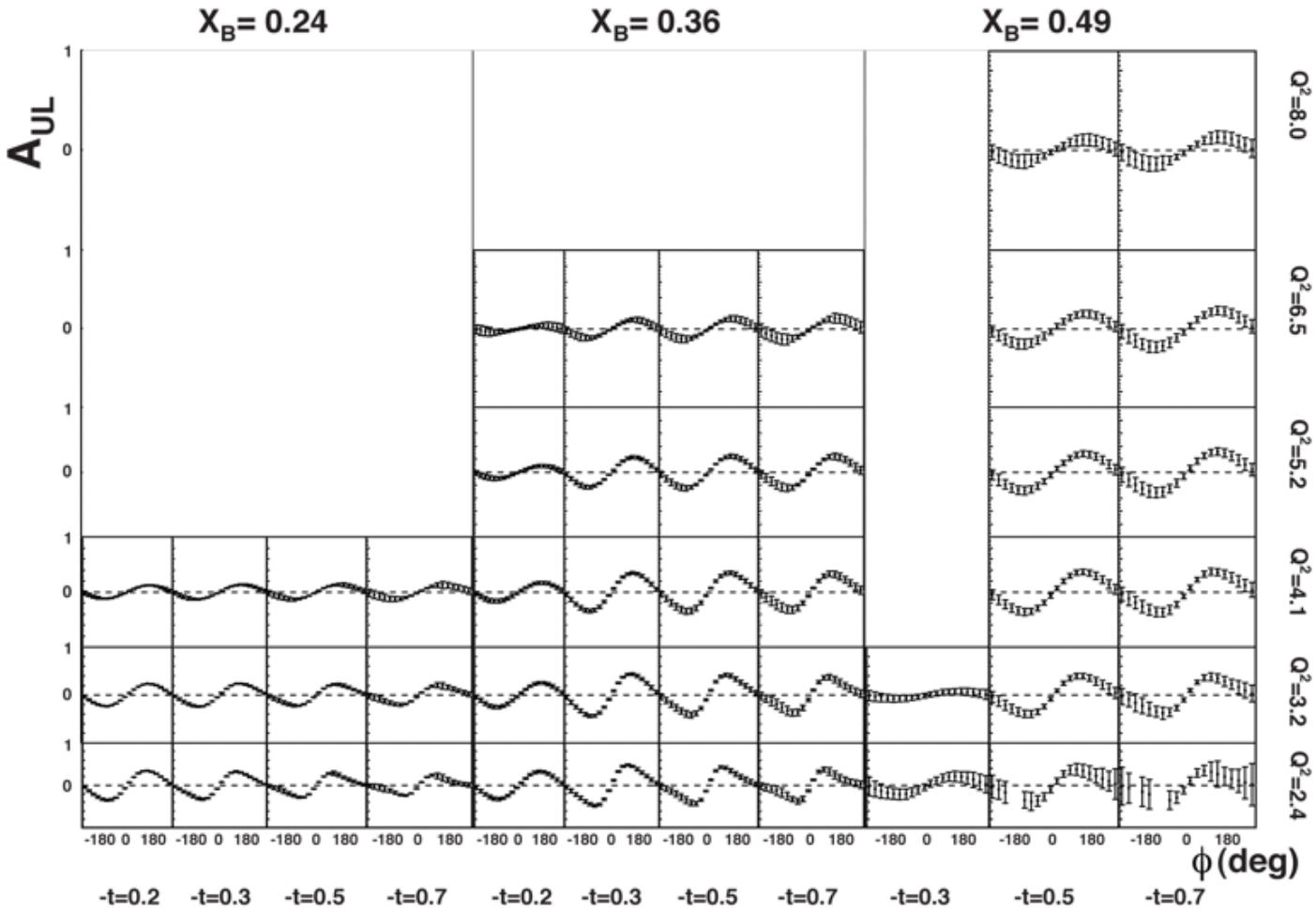
Extracted $H(\xi, \xi, t)$ and corresponding transverse profile





Proton DVCS TSA A_{UL}

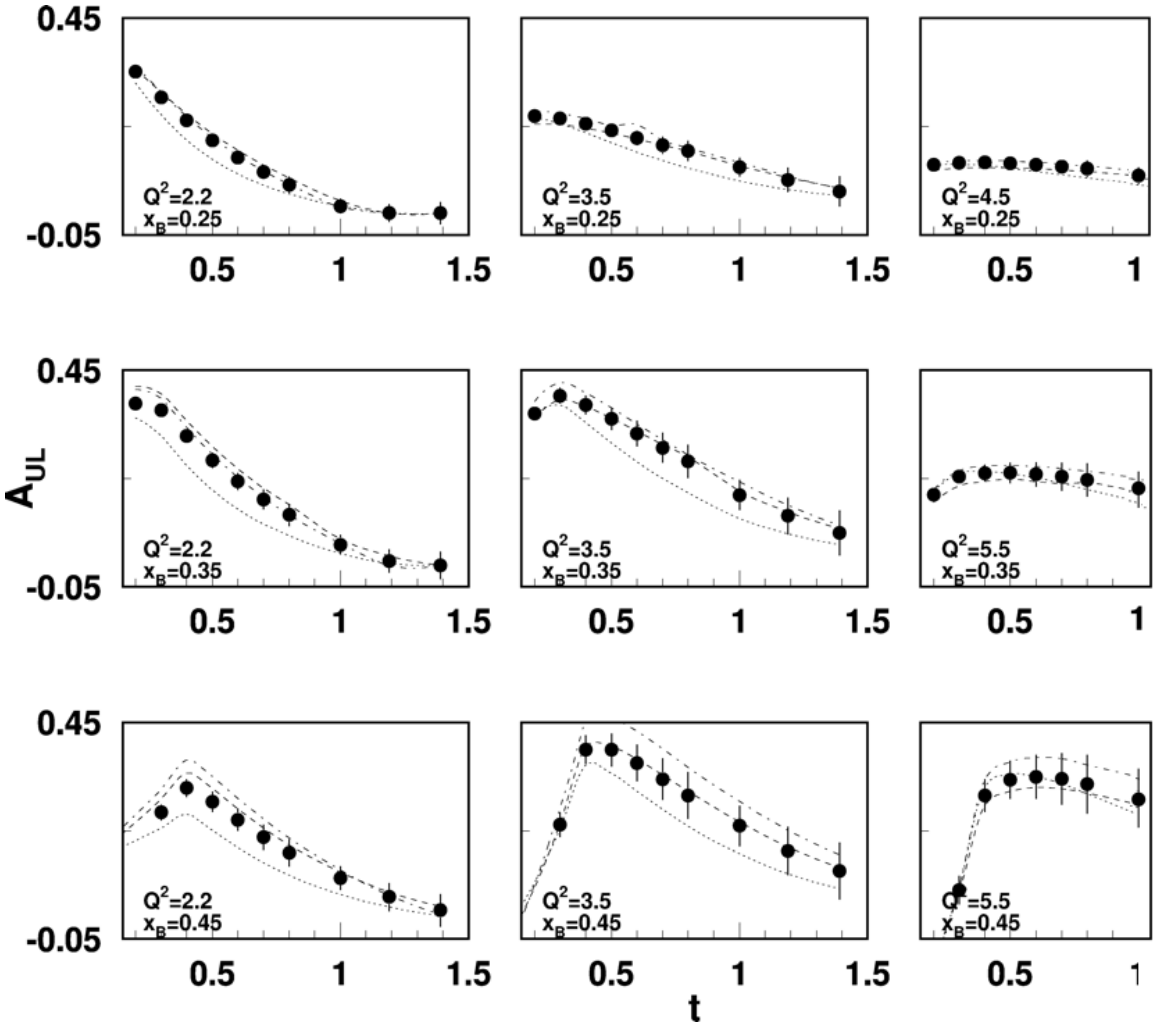
120 days @ $\mathcal{L} = 2 \times 10^{35}$ cm^{-2}s^{-1} with 80% polarized NH_3



Statistical uncertainties from 2 % (low Q^2) to 10 % (high Q^2)

Proton DVCS TSA A_{UL}

120 days @ $\mathcal{L} = 2 \times 10^{35}$ cm^{-2}s^{-1} with 80% polarized NH_3



Proton DVCS TSA A_{UL}

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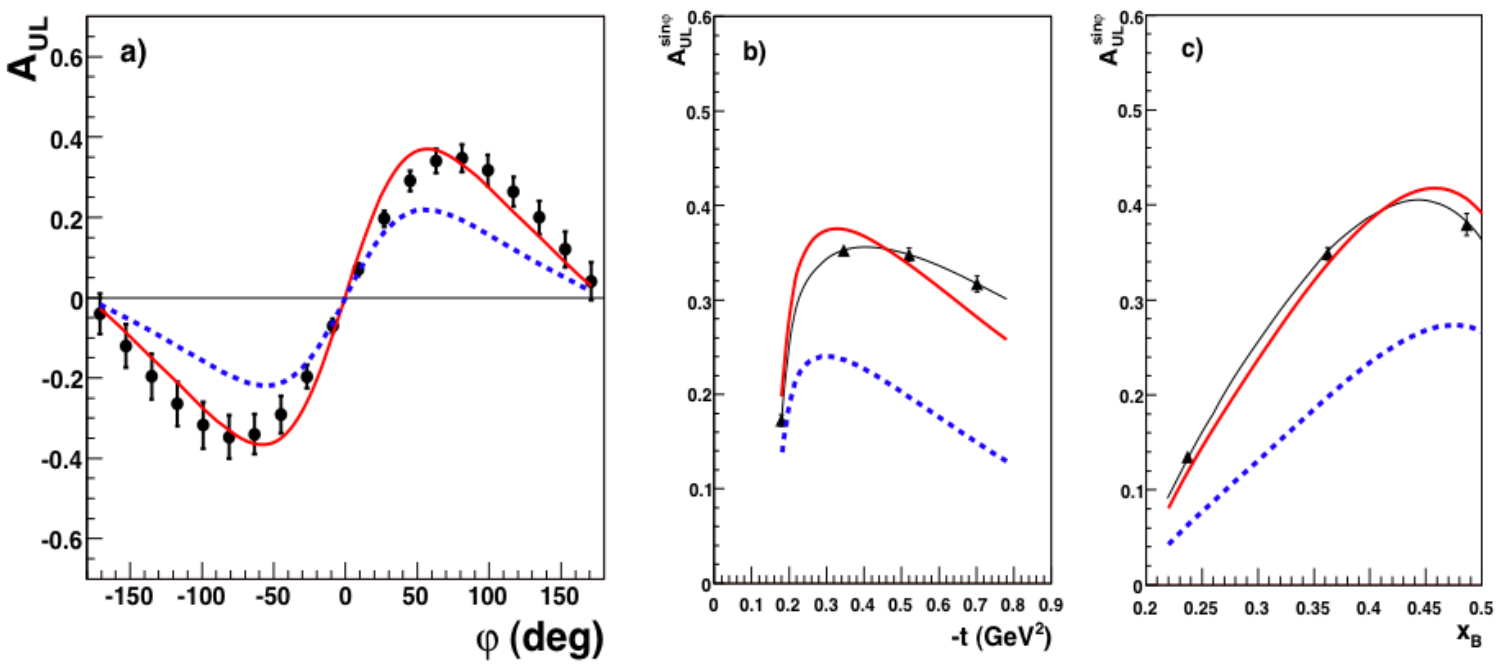


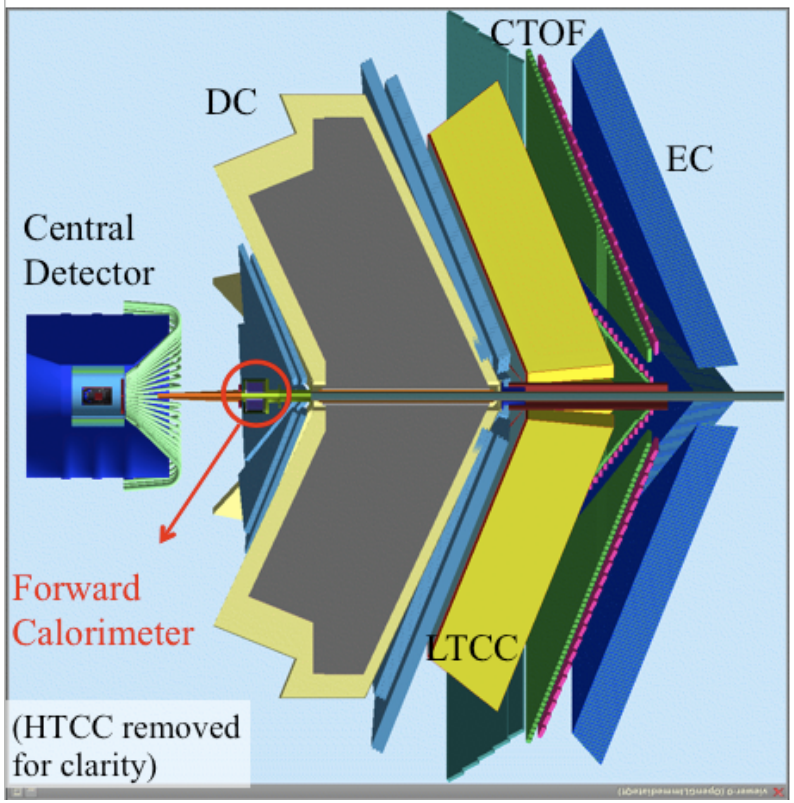
Red solid line : $E = \tilde{E} = 0$, blue dashed line : $\tilde{H} = 0$
$Q^2 = 4.1$ GeV^2, $x_B = 0.36$ (left and middle), $-t = 0.52$ GeV^2 (left and right)

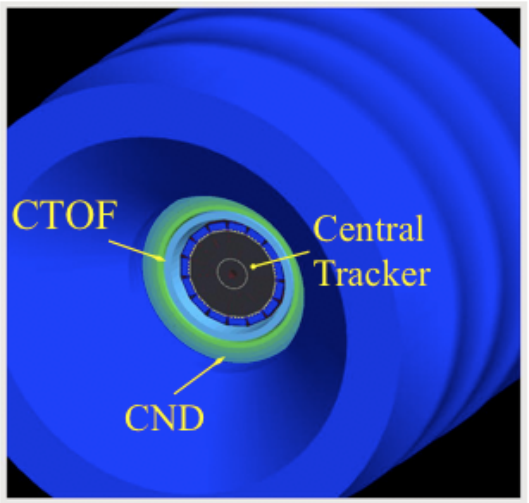
GPD program

Neutron DVCS

Neutron DVCS setup

For the detection of the scattered electron and of the DVCS photon: CLAS12 + Forward Calorimeter



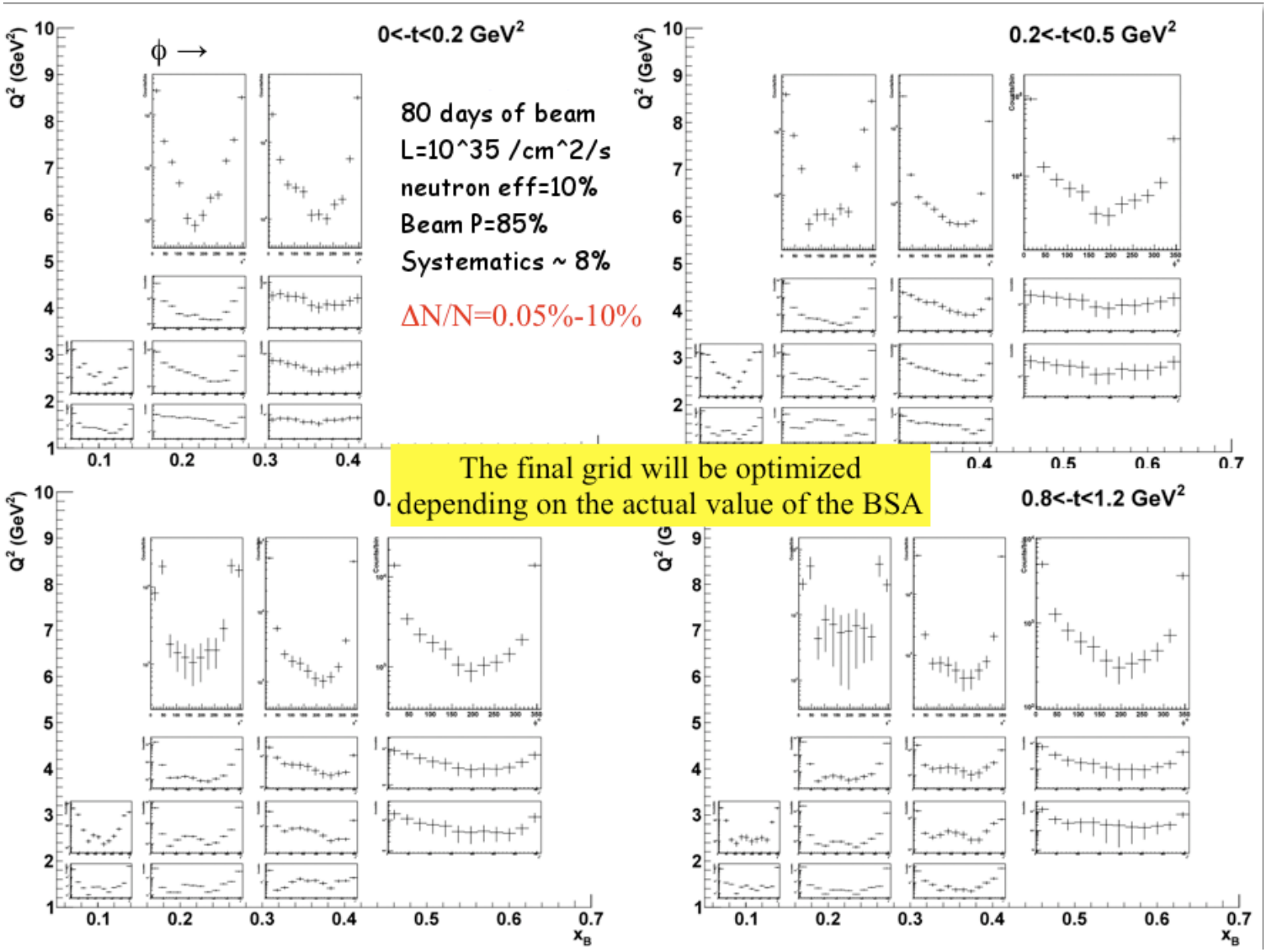


For the detection of the recoil neutron: Central Neutron Detector (CND)

Detection efficiency : 7 to 10 %

Acceptance for charged particles:
- **Central (CD), $40^o<\theta<135^o$**
- **Forward (FD), $5^o<\theta<40^o$**

Acceptance for photons:
- **FC $2.5^o<\theta< 5^o$**
- **EC, $5^o<\theta<40^o$**



GPD program

Other highlights

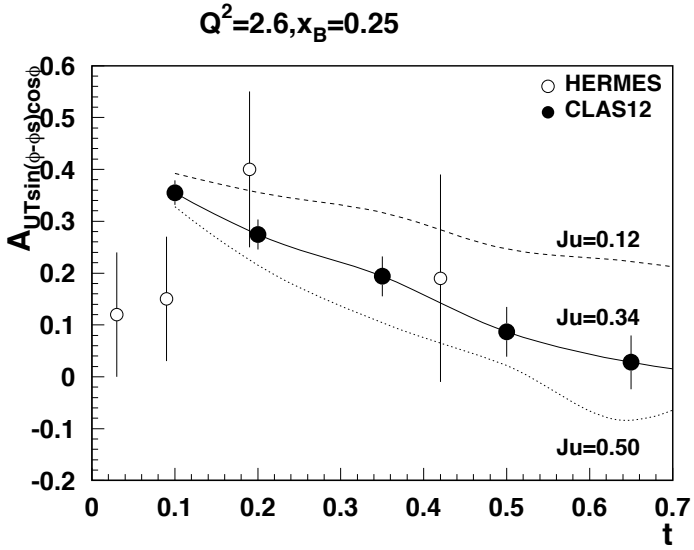
Transverse target asymmetries A_{UT}, DVCS & DVMP

More on angular momentum

DVCS with frozen HD-ice

$x_B \approx 0.25$

$Q^2 \approx 2.6$ GeV^2

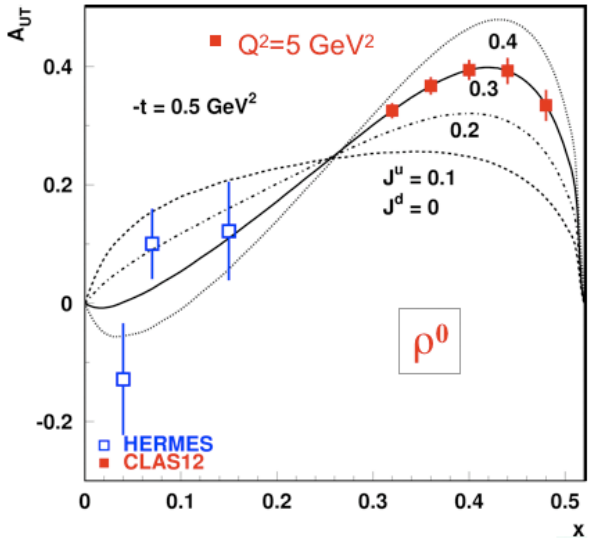


Exclusive ρ^0 production (hydrogen target)

$A_{UT} \sim \Delta_\perp \mathrm{Im} AB^*$

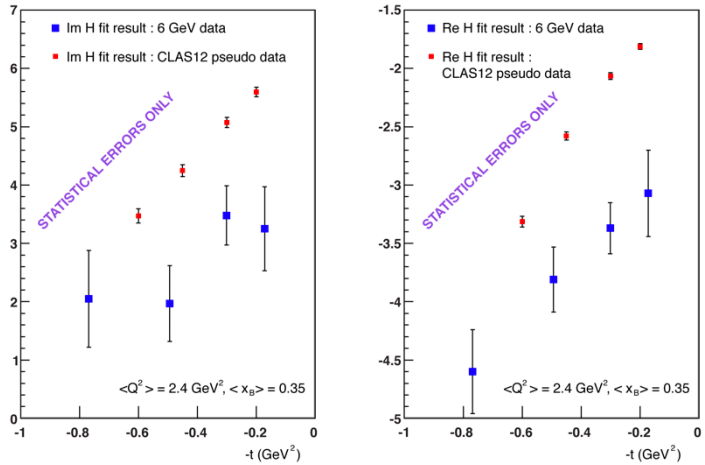
$A \sim 2H^u + H^d$

$B \sim 2E^u + E^d$

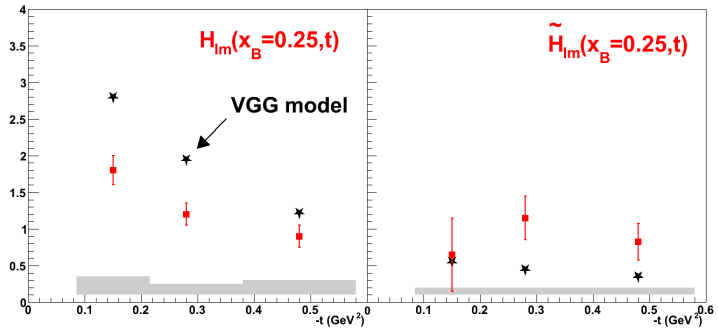


GPD Extraction

Efforts towards GPD extraction

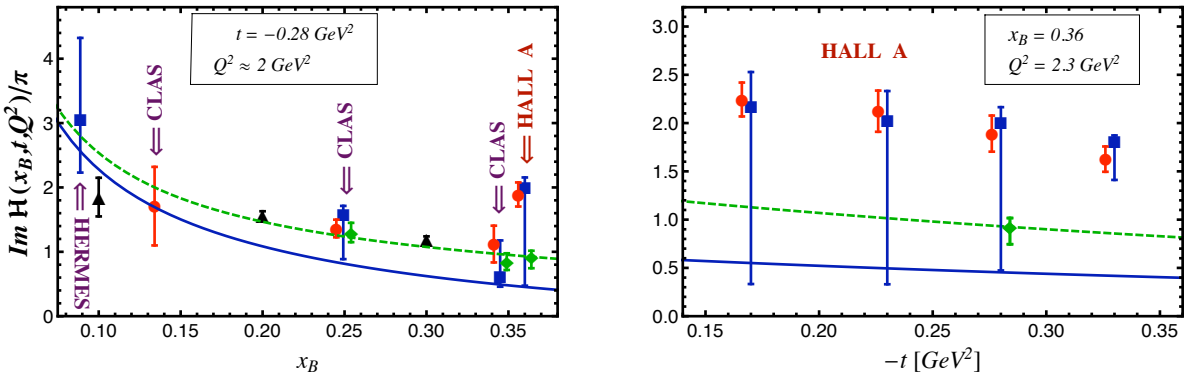


H. Moutarde, **PRD 79** (2009) 094021



M. Guidal **PLB 689** (2010) 156

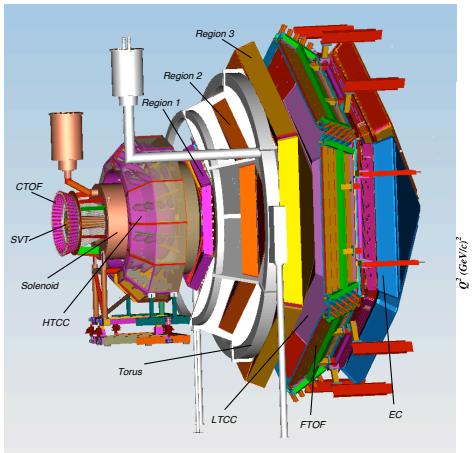
K. Kumericki & D. Mueller, arXiv:1008.2762

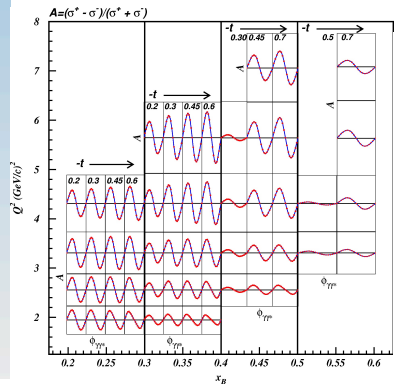


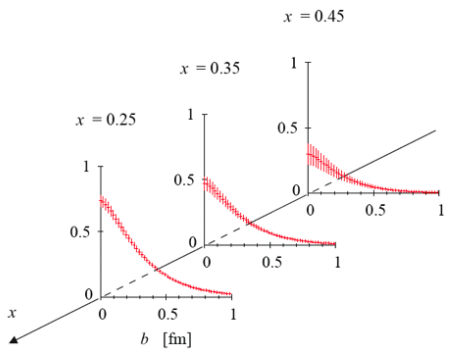
Conclusion

Summary and Prospects

- Deeply Virtual Compton Scattering on proton and neutron
- Flavor separation with Deeply Virtual Meson Production
- Valence quark tomography with global GPD extraction
- Also tomography of other hadrons
- An option of (polarized) positrons beam is also considered
- Sea and gluon tomography with Electron Ion Collider

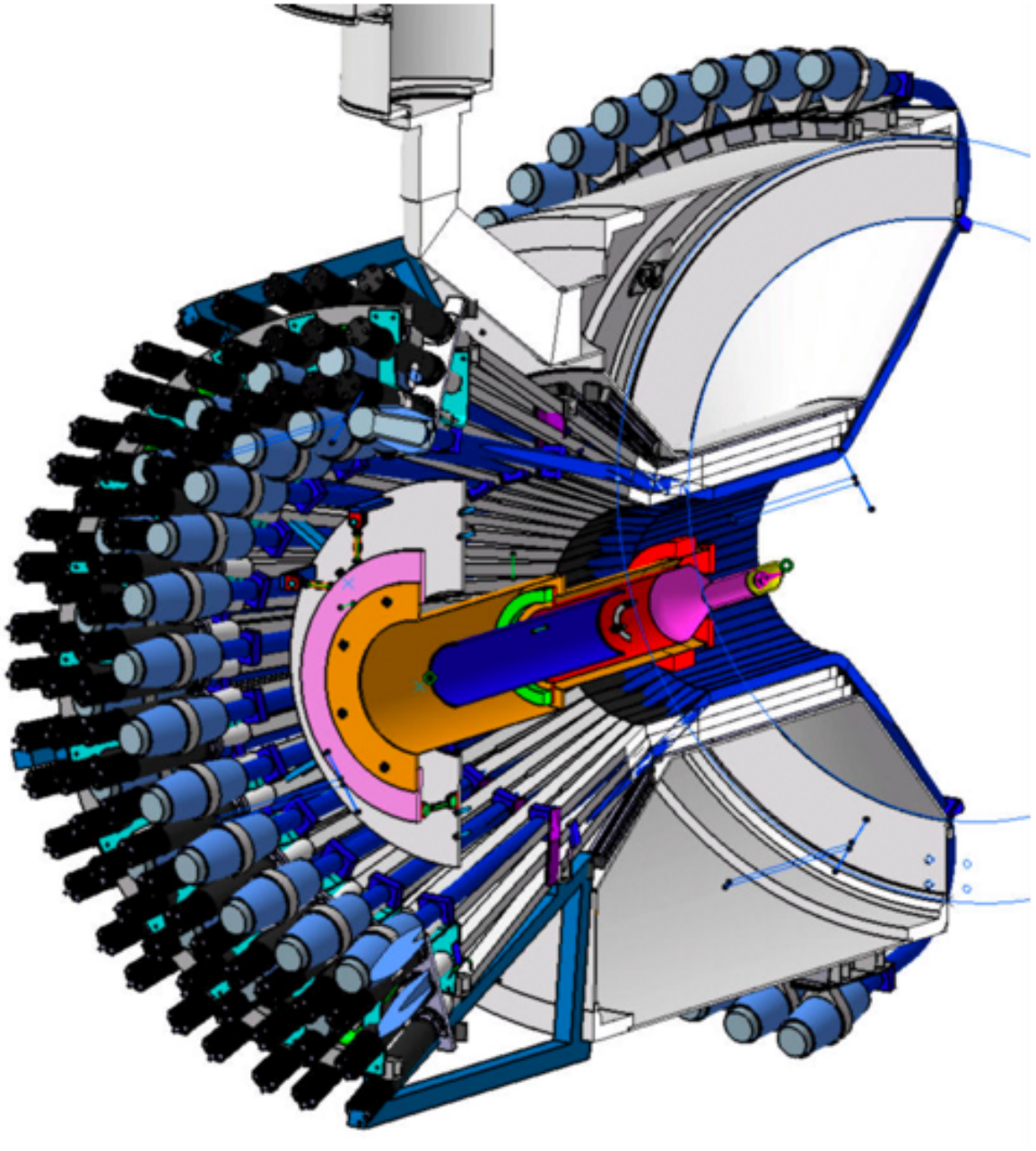






Additional slides

Mechanics and integration



Positron beam option